



ISB 2013
BRAZIL

XXIV CONGRESS OF THE INTERNATIONAL
SOCIETY OF BIOMECHANICS

XV BRAZILIAN CONGRESS
OF BIOMECHANICS

EMG DRIVEN MODEL OF THE LUMBAR SPINE DURING FLEXION, BENDING AND ROTATION USING OPENSIM

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SUMMARY

This study utilised the OpenSim platform to develop an EMG driven model of the lumbar spine by expanding an existing model and incorporating a plugin to represent intervertebral stiffness. Subject-specific kinematic data and surface EMG activity were recorded from 4 subjects during flexion and extension, lateral bending, and axial rotation. The model was used to predict muscle excitation patterns necessary to produce the recorded motions, and the patterns were compared with the recorded EMG data. The model was then driven with the recorded EMG data, and new excitation patterns were calculated for the deep muscles for which EMG data was not available. Simulations were conducted for intervertebral lumbar stiffness corresponding to preloading of 0N, 250N and 500N. The model-predicted excitation patterns were most comparable to recorded EMG data for the flexion and extension motions. Excitation levels predicted for all motions were sensitive to the applied preload. Although activation patterns remained similar, there was a substantial variation in model-predicted muscle excitation levels with change in intervertebral stiffness.

INTRODUCTION

OpenSim is a musculoskeletal modelling tool which allows development and analysis of complex biomechanical models which can be used to predict muscle excitation patterns for a given motion, and to drive models using recorded EMG data. The application of OpenSim in this manner has been mostly used in the area of gait analysis to date, and has received limited attention in the field of spinal modelling. The aim of this study was to develop an EMG-driven model of the lumbar spine using the OpenSim platform. The model was used to predict muscle excitation patterns using subject specific kinematics, with and without the inclusion of EMG signals acquired from primary actuators of the spine during flexion and extension, lateral bending, and axial rotation.

METHODS

Experimental methods: Four healthy subjects (2 male) participated in the study. Ethical approval was obtained from the UCD Human Research Ethics Committee. Surface electromyographic (EMG) data was recorded during the

flexion and extension, lateral bending, and axial rotation using the Trigno Wireless Electrode system (Delsys Inc., Boston, MA, USA). EMG signals were recorded from the left and right multifidus, iliocostalis, latissimus dorsi, rectus abdominis, and external oblique muscle groups. Full body kinematics and ground reaction forces were recorded using the CODA system (Codamotion Solutions, Leicestershire UK). To allow normalization of the EMG data, EMG signals were first recorded during isolated maximum voluntary contraction (MVC) of each of muscle group. Each subject performed three 5s isometric MVC contractions, separated by 30s, of the target muscle group. Subjects repeated each of the three motions, flexion and extension, lateral bending (left & right), and axial rotation (left & right), 5 times. Each motion was performed over 4 seconds. During flexion and extension, 2 seconds flexion were performed starting from a neutral standing position, followed by 2 seconds extension. The subject followed similar instructions for lateral bending and rotation. The protocol was repeated while holding a 10kg weight against the chest.

Model simulation: A model of lumbar spine, torso and legs incorporating full muscle architecture and intervertebral stiffness was constructed in OpenSim⁽¹⁻³⁾. Three lumbar intervertebral stiffness matrices measured using no preload, and preloads of 250N and 500N⁽⁴⁾, typical of spinal loading during sitting and standing, were examined in this study. The model was scaled to each individual subject's dimensions and weight. Subject specific kinematics and ground reaction forces recorded with the CODA system, were applied to the model. The computed muscle control (CMC) algorithm in OpenSim which minimises the sum of squared muscles excitations was then used to predict the muscle excitation patterns required by each muscle group to produce the input kinematic patterns for each motion. The CMC procedure was repeated while driving the model using muscle excitation patterns derived from the normalized RMS values of the experimentally recorded EMG data. The CMC algorithm was then used to predict the new excitation patterns for the remaining muscles for which EMG data was not available.

RESULTS AND DISCUSSION

Predicted muscle excitation levels and patterns were closest to the experimentally recorded EMG data during flexion and

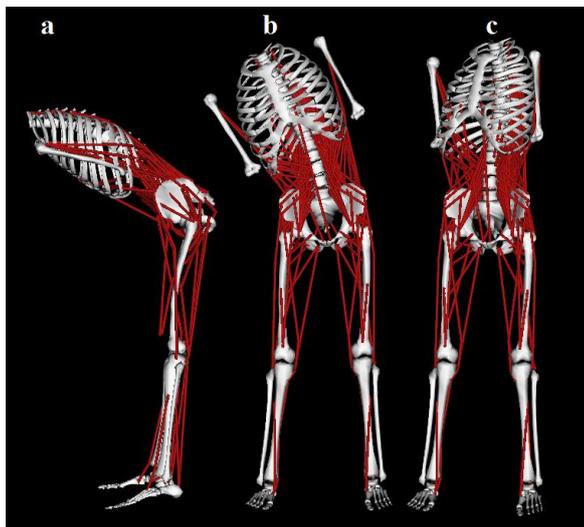


Figure 1: OpenSim Model during a) flexion, b) lateral bending and c) axial rotation.

extension, Figure 2 and Table 1. Predicted excitation patterns during lateral bending and axial rotation were similar to recorded data, but maximum amplitudes were generally higher in the model-predicted data than in recorded data. For all motions examined, a delay was noted between the time of maximal activation of the multifidus when comparing predicted and measured excitation patterns, Figure 2. In other muscles the time of maximal activation was similar in the model-predicted and measured EMG data. Certain trends emerged for the different muscle groups when analyzing the variation with intervertebral stiffness in the model. Higher maximum excitation levels were noted in the majority of muscle groups with increasing preload, with the exception of the longissimus and quadratus lumborum muscles. When the model was driven with the measured EMG data, the maximum activation of both muscle groups was highest with no applied preload, and lowest with 500N preload. Excitation amplitudes varied substantially when comparing models with and without lumbar preload. For models with preloads of 250N and 500N, amplitudes remained similar. For muscles not driven by EMG data, model-predicted excitation amplitudes changed, but excitation patterns remained similar when comparing values with and without the inclusion of measured EMG data for other muscles in the model. This indicates that regardless of the changes induced in the EMG driven muscles, the CMC algorithm chose to apply similar excitation patterns to the remaining muscle groups.

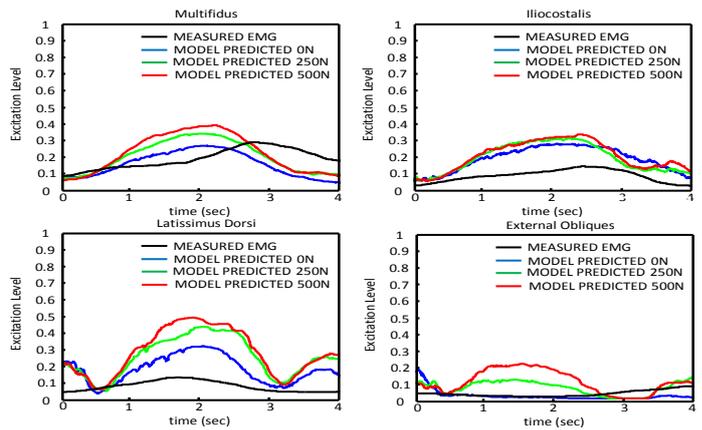
CONCLUSIONS

A model of the Lumbar Spine has been developed in OpenSim, capable of predicting muscle excitation patterns for subject specific motions including flexion and extension, lateral bending and axial rotation, both with and without the

Table 1: Measured EMG Vs Predicted Excitation – Maximum excitation levels during flexion/extension for iliocostalis(IL), latissimus dorsi (LD), multifidus (MF), rectus abdominis (RA) and external obliques (EO) for measured EMG and predicted muscle excitation for preloads of 0 N, 250 N and 500 N.

	IL	LD	MF	RA	EO
Measured EMG	0.2	0.22	0.3	0.1	0.05
0N Preload	0.3	0.27	0.23	0.1	0.05
250N Preload	0.3	0.4	0.33	0.7	0.11
500N Preload	0.3	0.45	0.38	0.9	0.23

FLEXION/EXTENSION



LATERAL BENDING

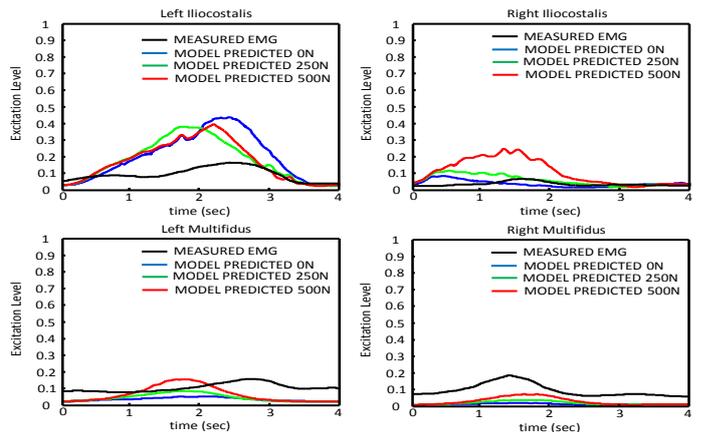


Figure 2: Measured EMG vs model-predicted excitation for key muscle groups during flexion/extension and lateral bending for representative subject 1.

inclusion of EMG-derived muscle excitation patterns. Examined muscle groups showed strong similarities between predicted and measured muscle excitation patterns and values. OpenSim demonstrated an adjustment of predicted excitation amplitudes for muscles not driven by EMG data in EMG driven models. The results also show a variation in predicted muscle excitation levels based on the intervertebral stiffness values applied to the model.

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Table 2: Model-Predicted Excitation Vs EMG Driven Model-Predicted Excitation,– Maximum excitation levels during flexion/extension for longissimus (LG), psoas (PS), quadrates Lumborum (QL) and internal obliques (IO) for preloads of 0 N, 250 N and 500 N.

		LG	PS	QL	IO
No EMG	0N Preload	0.2	0.05	0.05	0.15
	250N Preload	0.3	0.05	0.08	0.3
	500N Preload	0.32	0.05	0.1	0.3
EMG Driven	0N Preload	0.4	0.05	0.2	0.4
	250N Preload	0.25	0.2	0.15	0.4
	500N Preload	0.22	0.3	0.15	0.4